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22E(3) NACA 0015 DATA (THREE-DIMENSIONAL)

INTRODUCTION

The tests described herein were carried out in the University of Glasgow's 2.13m × 1.61m 'Handley Page' wind tunnel which is a low-speed closed-return type. The test model was a straight wing with a NACA 0015 cross-section and had simple solids of revolution at its tips. Because the lift behaviour at low aspect-ratios (AR) is quite different from that at high aspect ratios, particularly when AR is less than 2.0, the AR of this model was chosen as 3.0 to avoid strong three-dimensional effects at the mid-span in steady flow. When testing in a closed working section, it is very important to reduce the wall effects. In order to diminish the effect of upwash on the angle attack near the wing tips of the model and to reduce the blockage effect to minimum, the model size was carefully determined. The final overall dimensions were 126cm × 42cm which resulted in a variation of model blockage from a minimum of 2.6% to a maximum of 11.35% (not including the fairing of struts) and a model span to tunnel width ratio of 0.592. According to previous studies of the blockage effect for 2-D dynamic stall testing, these dimensions were considered acceptable. The model was supported on three struts, as shown in Fig. 7. These were, in turn, connected to the main support structure and actuation mechanism which was situated below the tunnel. Movement of the model was produced by displacement of the two rear struts and the model was pivoted about the quarter chord position on a tool steel shaft connected to the front support via two self-aligning bearings. The model was constructed with an aluminium framework of ribs and stringers and an outer epoxy glass fibre skin. Figure 8 illustrates this construction.

Altogether, 192 pressure transducers were placed within the model predominantly to the starboard side. There were six chordal distributions at various spanwise locations, each of which had 30 transducers. In the region of the tip, additional transducers were placed between the above mentioned sections to provide a better assessment of the tip vortex movement and structure. In order to check on the overall symmetry of the flow, two transducers were placed on the left side of the wing in corresponding positions to their counterparts on the starboard side. Additionally three accelerometers were embedded in the wing, two of which were at the rear tip locations and a final one mounted centrally. Details of the transducer distribution is given Table 12.

Four particular types of tests were considered in the study. These were static tests, ramp up tests, ramp down tests and sinusoidal tests. In all cases, the model was rotated about its quarter-chord axis to achieve the desired motion type. In the static tests, the straight wing was positioned at the incidence at which the first set of data was to be recorded. Usually, this was approximately -5°. The model's angle of attack was then increased in steps of 1° up to 42° allowing an appropriate settling time at each angle. During a ramp test, the straight wing was rotated over a preset arc at a constant pitch-rate. For the lower pitch rates, excellent ramp functions were obtained but, at the higher values, the starting and stopping sequences induced non-linearities. The ramp motion was repeated several times at each pitch rate and data from 4 cycles of motion were recorded. These were then averaged to produce the results presented here. In the sinusoidal tests, the model was pitched about a mean angle in such a manner that its angle of attack varied sinusoidally with time. An AMSTRAD function generator controlled the mean angle, amplitude and frequency and 8 cycles of motion were recorded. Once again, these were averaged to provide the results presented in this report.

FORMULARY

1 General Description of model

1.1	Designation	Model 16
1.2	Type	Full Wing
1.3	Derivation	Rectangular Wing
1.4	Additional remarks	None
1.5	References	11

2 Model Geometry

2.1	Planform	Rectangular Wing (see Fig. 8)
2.2	Aspect ratio	3.0
2.3	Leading edge sweep	None
2.4	Trailing edge sweep	None
2.5	Taper ratio	No Taper
2.6	Twist	No Twist
2.7	Wing centreline chord	0.42m
2.8	Semi-span of model	0.63m
2.9	Area of planform	0.516m^2 gross wing area
2.10	Location of reference sections and definition of profiles	Mid-span, NACA 0015 profile

2.11	Lofting procedure between reference sections	Constant section
2.12	Form of wing-body junction	None
2.13	Form of wing tip	Solid of revolution
2.14	Control surface details	None
2.15	Additional remarks	None
2.16	References	11

3 Wind Tunnel

3.1	Designation	University of Glasgow 'Handley-Page'
3.2	Type of tunnel	Closed section, closed return, atmospheric
3.3	Test section dimensions	2.13m (width) x 1.61m (height) x (length)
3.4	Type of roof and floor	Closed – vented at downstream end of working section
3.5	Type of side walls	Closed - vented at downstream end of working section
3.6	Ventilation geometry	60 rectangular slots (0.028m x0.055m) on floor, roof and walls downstream of working section. 13 rectangular slots (0.028m x 0.105m) at same section on angled surfaces.
3.7	Thickness of side wall boundary layer	Unknown
3.8	Thickness of boundary layers at roof and floor	Unknown
3.9	Method of measuring velocity	Working section and settling chamber static pressure tappings related to wind tunnel speed calibration
3.10	Flow angularity	Not available
3.11	Uniformity of velocity over test section	Dynamic pressure constant to within 1% over a $1.5m^2$ reference plane normal to the flow axis in the working section
3.12	Sources and levels of noise or turbulence in empty tunnel	Not available
3.13	Tunnel resonances	Not available
3.14	Additional remarks	None
3.15	References on tunnel	8

4 Model motion

4.1	General description	Four motion types: Static, Linear Ramp Up, Linear Ramp Down and Sinusoidal. All incidence variations about quarter chord.
4.2	Natural frequencies and normal modes of model and support system	Not available. Accelerometers located as shown in Fig 8 and outputs contained in logged data (See table 14)

5 Test Conditions

5.1	Model planform area/tunnel area	0.173
5.2	Model span/tunnel height	0.782
5.3	Blockage	Function of angle of attack 2.6% - 11.35%
5.4	Position of model in tunnel	Horizontal on tunnel centre-line. Mounted through floor. (see Fig. 7)
5.5	Range of velocities	45 m/s to 55 m/s
5.6	Range of tunnel total pressure	Approximately 102.5kPa to 103kPa
5.7	Range of tunnel total temperature	Approximately 293K to 306K
5.8	Range of model steady or mean incidence	-5° to 42°
5.9	Definition of model incidence	Deviation of chord line from tunnel centreline
5.10	Position of transition, if free	Not available
5.11	Position and type of trip, if transition fixed	None
5.12	Flow instabilities during tests	Not available
5.13	Changes to mean shape of model due to steady aerodynamic load	Not available

5.14	Additional remarks	None
5.15	References describing tests	11

6 Measurements and Observations

6.1	Steady pressures for the mean conditions	Yes
6.2	Steady pressures for small changes from the mean conditions	No
6.3	Quasi-steady pressures	No
6.4	Unsteady pressures	Yes
6.5	Steady section forces for the mean conditions by integration of pressures	Yes
6.6	Steady section forces for small changes from the mean conditions by integration	No
6.7	Quasi-steady section forces by integration	No
6.8	Unsteady section forces by integration	Yes
6.9	Measurement of actual motion at points of model	No
6.10	Observation or measurement of boundary layer properties	No
6.11	Visualisation of surface flow	No
6.12	Visualisation of shock wave movements	No
6.13	Additional remarks	None

7 Instrumentation

7.1	Steady pressure	
	7.1.1 Position of orifices spanwise and chordwise	See Table 12
	7.1.2 Type of measuring system	192 individual Kulite sensors mounted close to wing surface connected to 200 parallel channel data acquisition system.
7.2	Unsteady pressure	
	7.2.1 Position of orifices spanwise and chordwise	See Table 12.
	7.2.2 Diameter of orifices	1.0mm
	7.2.3 Type of measuring system	192 Individual Kulite sensors mounted close to wing surface connected to 200 parallel channel data acquisition system.
	7.2.4 Type of transducers	Kulite CJQH-187 differential
	7.2.5 Principle and accuracy of calibration	Steady state sensitivity from applied reference and calibration procedures. Accuracy as stated by manufacturer.
7.3	Model motion	
	7.3.1 Method of measuring motion reference coordinate	Quarter chord location specified by manufacture
	7.3.2 Method of determining spatial mode of motion	Feedback from optical shaft encoder.
	7.3.3 Accuracy of measured motion	0.02°
7.4	Processing of unsteady measurements	
	7.4.1 Method of acquiring and processing measurements	192 Individual Kulite sensors mounted close to wing surface connected to 200 parallel channel Bakker Electronics BE256 sample and hold modules. Signal conditioning modules on each individual channel. Gain and offset removal automatic. Acquired data downloaded to PC.
	7.4.2 Type of analysis	Phase averaging of cycles. Four cycles for ramp function tests, eight for sinusoidal tests.
	7.4.3 Unsteady pressure quantities obtained and accuracies achieved	Basic unsteady pressure signal. Cycle repeatability variable depending on amplitude and reduced frequency.
	7.4.4 Method of integration to obtain forces	Trapezoidal rule

7.5	Additional remarks	None
7.6	References on techniques	None

8 Data presentation

8.1	Test cases for which data could be made available	Four motion types: Static, Linear Ramp Up, Linear Ramp Down and Sinusoidal. Tests cover a range of incidence and reduced frequency/pitch rate. In total 100 test cases. All incidence variations about quarter chord.
8.2	Test cases for which data are included in this document	Four motion types: Static, Linear Ramp Up, Linear Ramp Down and Sinusoidal. 10 test cases as detailed in Tables 9, 10 and 11. A series of plots are also presented which are illustrative of the data supplied in electronic form. Figure 9 illustrates the integrated normal force coefficients at six span locations on the wing for test case 11441 (file: ntm11441.dat). In the figure, these are contrasted with the static test case 00011(file: ntm 00011.dat). Figure 10 presents the integrated pitching moment coefficients at the same span positions for the ramp-up case 20962 (file: ntm20962.dat). Again, a comparison is made with the static case. Figure 11 presents chordwise pressure distributions at three span locations and at four angles of incidence for the ramp-down case 30681 (file: ntm30681.dat). Finally, in Figs12, 13 and 14, the variation of upper surface chordal pressure distribution with changing incidence is presented at the 57.14%, 80% and 97.2% span positions for the ramp-up test case 21042 (file: cp21042.dat).
8.3	Steady pressures	For static case
8.4	Quasi-steady or steady perturbation pressures	No
8.5	Unsteady pressures	For all dynamic cases
8.6	Steady forces or moments	For static case
8.7	Quasi-steady or unsteady perturbation forces	No
8.8	Unsteady forces and moments	For all dynamic cases
8.9	Other forms in which data could be made available	None
8.10	Reference giving other representations of data	N/A

9 Comments on data

9.1	Accuracy	
	9.1.1 Mach number	±0.5%
	9.1.2 Steady incidence	±0.02°
	9.1.3 Reduced frequency	±0.5%
	9.1.4 Steady pressure coefficients	±0.5%
	9.1.5 Steady pressure derivatives	Not estimated
	9.1.6 Unsteady pressure coefficients	±0.5%
9.2	Sensitivity to small changes of parameter	N/A
9.3	Non-linearities	N/A
9.4	Influence of tunnel total pressure	Not examined
9.5	Effects on data of uncertainty, or variation, in mode of model motion	N/A
9.6	Wall interference corrections	None
9.7	Other relevant tests on same model	None
9.8	Relevant tests on other models of nominally the same shapes	None
9.9	Any remarks relevant to comparison between experiment and theory	None
9.10	Additional remarks	The electronic data supplied with this report comprise three file types. The first type of file contains the wing co-ordinates, in the

form of pressure transducer locations, as specified in Table 12. There is only one file of this type and it is identified by the name 3dmcrd16.dat. The file contains four numbers in the first line followed by the three columns of 192 co-ordinates presented in Table 12. The numbers in the first line represent, in order, number of transducers in one chordal array, number of upper surface transducers in one chordal array, number of chordal arrays, total number of transducers. It should be noted that there are six chordal arrays of thirty transducers giving a total of 180 transducers. The remaining transducers are distributed in the region of the tip vortex, to provide definition of the pressure response there, and on the other side of the wing to indicate flow symmetry.

The second type of file is designated cp'case number'.dat (e.g. cp00011.dat) and there is one of these files for each test case. This type of file consists mainly of the measured pressure coefficient data but also contains all other information relating to the test case. The first twenty-two values in each file are known as the Run Information Block (RIB) and correspond to the RIB locations 0-21 detailed in Table 13. It should be noted that RIB location 19 is set to zero because the dynamic pressure information is contained elsewhere in the file. Following the RIB, the next value in the file is the number, N, of data samples. For all cases, other than the static case, N is set to 201. For the static case, 00011, the value is 48. After this value, the file contains N rows of 200 data values. The content of each row is illustrated in Table 14.

The FORTRAN write statement used to produce the cp*****.dat files is illustrated below.

Note:
```
      DIMENSION RINFO(22), CPMS1(200,201)
      WRITE(9,*)RINFO
      WRITE(9,*)NUMBER
      DO 222 I=1,NUMBER
      WRITE(9,*)(CPMS1(J,I),J=1,200)
222   CONTINUE
```

The final file type, designated ntm'case number'.dat (e.g. ntm00011.dat), contains integrated values of Cn, Ct and Cm (quarter chord) for each of the chordal arrays and for the entire wing. There is one of these files for each test case. The first value in the file corresponds to N in the corresponding cp file and this indicates the number of rows to follow. The contents of each subsequent row are described in Table 15 and the FORTRAN write statement used to produce the file is given below.

```
      WRITE(8,*)NUMBER
      DO 15 KK =1,NUMBER
      WRITE(8,*)ANG(KK),(CN(I),I=1,NSECT),(CT(I),I=1,
     * NSECT), (CM(I),I=1,NSECT),CN3D,CT3D,CM3D
15    CONTINUE
```

9.11 References on discussion of data — 12, 13

10 Personal contact for further information

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APPENDIX A

Parameter 14, which describes the number of samples, is important. This is essentially the number of time points at which data were sampled.

The data from the test case are then given. The test data for each sample are contained in a block consisting of the instantaneous dynamic pressure reading in Nm^{-2} followed by the pressure coefficient at each transducer location (from location 1 to location 35 in sequence) and finally the instantaneous incidence in degrees.

A program to read in the test data should therefore read in the run information block first. The rest of the information may then be read in according to the number of samples indicated by parameter number 14.

A sample MATLAB code fragment to read in the data is given below:

```
fid=fopen(fname);                //open data file
rib=fread(fid,'%g',128); //read in run information block (rib)...
//data is in '%g' general format, and there are 128 samples
nsamps=rib(14);           //extract number of data samples from rib
model_number=rib(30); //extract model number from rib
//model 15 (sikorsky) has 35 transducers, other models have 30...
if (model_number == 15) then
        nxducers=35;
else
        nxducers=30;
end
//model 12 (high AR NACA 0015 has chord length of 0.275m, others have //chord=0.55m
if (model_number==12) then
        chord=0.275;
else
        chord=0.55;
end
//read in data
for i = 1, nsamps;               //loop for number of samples...
        //construct non-dimensional time array....
        //ndt=tU/c, c=model chord
        ndt(i)=(i-1)*rib(23)/(chord*rib(18));
        q(i)=fread(fid,'%g',1);            //read in dynamic pressure
        cp((1,nxducers),i)=fread(fid,'%g',nxducers);       //read in pressure data
        alpha(i)=fread(fid,'%g',1);        //read in incidence
end
```

APPENDIX B

Parameter 14, which describes the number of samples, is important. This is essentially the number of time points at which data were sampled.

The data from the test case are then given. The test data for each sample are contained in a block consisting of the instantaneous dynamic pressure reading in Nm^{-2} followed by the pressure coefficient at each transducer location (from location 1 to location 30 in sequence) and finally the instantaneous incidence in degrees.

A program to read in the test data should therefore read in the run information block first. The rest of the information may then be read in according to the number of samples indicated by parameter number 14.

A sample MATLAB code fragment to read in the data is given below:

```
fid=fopen(fname);                //open data file

rib=fread(fid,'%g',128); //read in run information block (rib)...

//data is in '%g' general format, and there are 128 samples
nsamps=rib(14);          //extract number of data samples from rib
model_number=rib(30); //extract model number from rib
//model 15 (sikorsky) has 35 transducers, other models have 30...
if (model_number == 15) then
        nxducers=35;
else
        nxducers=30;
end
//model 12 (high AR NACA 0015 has chord length of 0.275m, others have //chord=0.55m
if (model_number==12) then
        chord=0.275;
else
        chord=0.55;
end
//read in data
for i = 1, nsamps;               //loop for number of samples...
        //construct non-dimensional time array....
        //ndt=tU/c, c=model chord
        ndt(i)=(i-1)*rib(23)/(chord*rib(18));
        q(i)=fread(fid,'%g',1);              //read in dynamic pressure
        cp((1,nxducers),i)=fread(fid,'%g',nxducers);        //read in pressure data
        alpha(i)=fread(fid,'%g',1);          //read in incidence
end
```

Table 1 Presented Test Cases

Section No	Model	No of Test Cases	Motion Type
1	Sikorsky SSC-AO9 (2D)	3	RU
2	NACA 0015, low aspect ratio (2D)	10	ST, RU, RD, S
	NACA 0015 high aspect ratio (2D)	16	ST, RU, RD, S
3	NACA 0015 (3D)	10	ST, RU, RD, S

Table 2 SSC-A09 Profiles Co-ordinates

x (% chord)	y upper (% chord)	y lower (% chord)
0.0	0	0
0.0199	0.2	-0.1454
0.0798	0.3946	-0.2869
0.1994	0.6482	-0.4573
0.2991	0.8029	-0.5446
0.4487	0.9868	-0.6445
0.6979	1.2392	-0.7703
0.9970	1.4921	-0.8877
1.5952	1.9076	-1.0704
2.1934	2.2500	-1.2175
2.7916	2.5445	-1.3447
3.3898	2.8039	-1.4588
3.9881	3.0369	-1.5631
4.5863	3.2494	-1.6594
5.1845	3.4449	-1.7487
5.7827	3.6249	-1.8314
6.7797	3.8903	-1.9568
7.7767	4.1143	-2.0691
8.7737	4.3016	-2.1706
9.7707	4.4583	-2.2638
11.2663	4.6504	-2.3910
12.7618	4.8054	-2.5064
14.2573	4.9345	-2.6124
15.7529	5.0444	-2.7104
17.2485	5.1385	-2.8013
18.7440	5.2184	-2.8853
20.2395	5.2860	-2.9628
21.7350	5.3427	-3.0339
23.2305	5.3911	-3.0988
24.7261	5.4322	-3.1579
27.7171	5.4958	-3.2594
30.7082	5.5369	-3.3402
33.6992	5.5564	-3.4007
37.6873	5.5494	-3.4506
41.6754	5.5039	-3.4637
43.6694	5.4663	-3.4558
45.6635	5.4182	-3.4376
47.6575	5.3595	-3.4087
49.6515	5.2899	-3.3683
51.6456	5.2093	-3.3165
53.6935	5.1176	-3.2532
55.6336	5.0149	-3.1790
57.6277	4.9009	-3.0949
59.6217	4.7755	-3.0018
61.6157	4.6381	-2.9002
63.6097	4.4875	-2.7904
65.6039	4.3220	-2.6720
67.5979	4.1391	-2.5448
69.5919	3.9368	-2.4088
71.5860	3.7140	-2.2642
73.5800	3.4719	-2.1121
75.5740	3.2138	-1.9540
77.5680	2.9445	-1.7918
79.5621	2.6681	-1.6272
81.5561	2.3871	-1.4617
83.5501	2.1012	-1.2957
85.5442	1.8089	-1.1289
87.5382	1.5093	-0.9598
89.5323	1.2051	-0.7863
91.5264	0.9046	-0.6081
93.5204	0.6229	-0.4290
95.5144	0.3849	-0.2610
97.5084	0.2288	-0.1325
98.5055	0.1987	-0.0992
99.5025	0.2135	-0.0863
100.0000	0.2408	-0.0803

Table 3 Pressure Transducer Location

There were 35 pressure transducers installed in the model, with 19 on the upper surface. Particular attention was given to a concentration around the leading edge. The transducer coordinates are as follows:

Transducer Number	x (% chord)	y (% chord)
1	98.4	0.19983
2	94.4	0.51594
3	87.5	1.51509
4	78.4	2.82985
5	67.8	4.11950
6	56.7	4.95535
7	46.13	5.40543
8	36.98	5.55342
9	30.10	5.53031
10	26.00	5.46219
11	19.10	5.23536
12	14.82	4.97868
13	10.20	4.51809
14	5.94	3.66964
15	2.50	2.40601
16	1.00	1.49445
17	0.50	1.04388
18	0.25	0.73581
19	0.12	0.46899
20	0.50	-0.67456
21	2.50	-1.28479
22	5.94	-1.85216
23	10.2	-2.30172
24	14.82	-2.65090
25	19.10	-2.90438
26	26.00	-3.20377
27	30.10	-3.32542
28	36.98	-3.44437
29	46.13	-3.43183
30	56.70	-3.13519
31	67.80	-2.53142
32	78.40	-1.72332
33	87.50	-0.96308
34	94.40	-0.35254
35	98.40	-0.10222

Table 4 Test Cases

Run Number	Reduced Pitch Rate	Incidence Range
15020021	0.04091	-1^o to 40^o
15020121	0.02035	-1^o to 40^o
15020201	0.00214	-1^o to 40^o

The nominal Mach and Reynolds numbers are 0.12 and $1.5x10^6$.

Table 5 Run Information Data

Parameter	Description		
1	run number		
2	test day		
3	test month		
4	test year		
5	temperature (^{o}C)		
6	pressure (mm Hg)		
7	test type:	0=static, 1=oscillatory, 2=ramp-up, 3=ramp-down	
8	ramp test:	requested pitch rate ($^{o}s^{-1}$)	(This is the desired pitch rate. However, actual pitch rate can be obtained from the logged data.)
	oscillatory test:	mean incidence (deg)	
9	ramp test:	ramp arc (deg)	
	oscillatory test:	amplitude (deg)	
10	ramp test:	linear pitch rate ($^{o}s^{-1}$)	
	oscillatory test:	oscillation frequency (Hz)	
11	sweeps per cycle	(This is the number of times all transducers are logged per cycle)	
12	values per cycle		
13	number of cycles		
14	total no. of samples		
15	no. of blocks on disc		
16	clock (irate)		
17	clock (iprset)		
18	sampling rate (Hz)		
19	dynamic pressure (Nm^{-2})		
20	Reynolds number		
21	Mach number		
22	ramp test: linear reduced pitch rate		
	oscillatory test:	reduced frequency	
23	free stream velocity (ms^{-1})		
24	blocks per cycle		
25	no. data points in unfilled silo		
26	data type: 1=averaged data, 2=unaveraged data		
27	no. processed blocks		
28	data type: 1=volts, 2=pressure coefficients		
29	dynamic pressure (Nm^{-2})		
30	model number		
31	coordinate file number		
32	ramp start angle (deg)		
33 to 64:	transducer calibration values		
65 to 96:	channel gain values		
97 to 128:	channel offset values		

Table 6 Pressure Transducer Location

The pressure transducers were positioned symmetrically on the upper and lower surfaces of the model. The transducer number and the chordwise position are listed below:

Transducer Number		Chordwise Station (%chord)
Upper Surface	Lower Surface	
1	30	98.0
2	29	95.0
3	28	83.0
4	27	70.0
5	26	59.0
6	25	50.0
7	24	37.0
8	23	26.0
9	22	17.0
10	21	10.0
11	20	5.0
12	19	2.5
13	18	1.0
14	17	0.25
15	16	0.025

Table 7 Test Cases for Low Aspect Ratio Model

Static test:

Run Number	Incidence Range
05000051	-1° to 30° to -1°

Ramp tests:

Run Number	Reduced Pitch Rate	Incidence Range
05025451	0.0116	-1° to 40°
05025491	0.0187	-1° to 40°
05025551	0.0274	-1° to 40°
05036461	-0.0119	40° to -1°
05036511	-0.0193	40° to -1°
05036581	-0.0277	40° to -1°

Oscillatory tests:

Run Number	Reduced Frequency	Mean Incidence	Amplitude
05014181	0.153	6°	10°
05014201	0.153	15°	10°
05014211	0.153	20°	10°

Table 8 Test Cases for High Aspect Ratio Model

Static test:

Run number	Incidence range
12001251	-1° to 30° to -1°

Ramp tests (clean leading edge):

Run Number	Reduced Pitch Rate	Incidence Range
12021761	0.0110	-1° to 40°
12021411	0.0188	-1° to 40°
12021441	0.0242	-1° to 40°
12031861	-0.0126	40° to -10°
12031901	-0.0192	40° to -10°
12031951	-0.0281	40° to -10°

Ramp tests (with leading edge sand strip):

Run Number	Reduced Pitch Rate	Incidence Range
12822001	0.0108	-1° to 40°
12822321	0.0190	-1° to 40°
12822101	0.0271	-1° to 40°
12832361	-0.0128	40° to -10°
12832141	-0.0197	40° to -10°
12832191	-0.0284	40° to -10°

Oscillatory tests:

Run Number	Reduced Frequency	Mean Incidence	Amplitude
12010712	0.167	6°	10°
12010732	0.167	15°	10°
12010772	0.167	20°	10°

Table 9 Static Test Case

Run No.	Incidence Range (°)	Reynolds No. x 10^{-6}	Sampling Frequency (Hz)
00011	-5~42	1.52	2000

Table 10 Ramp Test Cases

Run No.	Ramp Arc (°)	Pitch Rate (° s^{-1})	Reduced Pitch Rate	Reynolds No. × 10^{-6}	Sampling Frequency (Hz)
20912	- 5 ~ 39	160.24	0.0110	1.48	13790
20962	- 5 ~ 39	280.96	0.0190	1.48	22220
21042	- 5 ~ 39	404.44	0.0270	1.50	33330
30621	39 ~ -5	-161.12	- 0.012	1.37	15380
30681	39 ~ -5	-263.56	- 0.019	1.39	24390
30751	39 ~ -5	-380.37	- 0.028	1.38	33330

Table 11 Sinusoidal Test Cases

Run No.	Mean Angle (°)	Amplitude (°)	Reduced Frequency	Reynolds No. × 10^{-6}	Sampling Frequency (Hz)
11261	5	10	0.17	1.50	20830
11381	15	10	0.16	1.49	20830
11441	20	10	0.17	1.47	20830

Table 12 Pressure Transducer Location

No.	x/c	y/c	z/s
1	0.98	0.00504	0.57143
2	0.95	0.01008	0.57143
3	0.83	0.02856	0.57143
4	0.7	0.0458	0.57143
5	0.59	0.05806	0.57143
6	0.5	0.06618	0.57143
7	0.37	0.07376	0.57143
8	0.26	0.07454	0.57143
9	0.17	0.06911	0.57143
10	0.1	0.05854	0.57143
11	0.05	0.04443	0.57143
12	0.025	0.03268	0.57143
13	0.01	0.02129	0.57143
14	0.0025	0.01089	0.57143
15	0.00025	0.0035	0.57143
16	0.00025	-0.0035	0.57143
17	0.0025	-0.01089	0.57143
18	0.01	-0.02129	0.57143
19	0.025	-0.03268	0.57143
20	0.05	-0.04443	0.57143
21	0.1	-0.05854	0.57143
22	0.185	-0.07053	0.57143
23	0.26	-0.07454	0.57143
24	0.355	-0.07422	0.57143
25	0.49	-0.06695	0.57143
26	0.59	-0.05806	0.57143
27	0.7	-0.0458	0.57143
28	0.835	-0.02784	0.57143
29	0.95	-0.01008	0.57143
30	0.98	-0.00504	0.57143
31	0.98	0.00504	0.68175
32	0.95	0.01008	0.68175
33	0.83	0.02856	0.68175
34	0.7	0.0458	0.68175
35	0.59	0.05806	0.68175
36	0.5	0.06618	0.68175
37	0.37	0.07376	0.68175
38	0.26	0.07454	0.68175
39	0.17	0.06911	0.68175
40	0.1	0.05854	0.68175
41	0.05	0.04443	0.68175
42	0.025	0.03268	0.68175
43	0.01	0.02129	0.68175
44	0.0025	0.01089	0.68175
45	0.00025	0.0035	0.68175
46	0.00025	-0.0035	0.68175
47	0.0025	-0.01089	0.68175
48	0.01	-0.02129	0.68175
49	0.025	-0.03268	0.68175
50	0.05	-0.04443	0.68175
51	0.1	-0.05854	0.68175
52	0.185	-0.07053	0.68175
53	0.26	-0.07454	0.68175
54	0.355	-0.07422	0.68175
55	0.49	-0.06695	0.68175
56	0.59	-0.05806	0.68175
57	0.7	-0.0458	0.68175
58	0.835	-0.02784	0.68175

No.	x/c	y/c	z/s
59	0.95	-0.01008	0.68175
60	0.98	-0.00504	0.68175
61	0.98	0.00504	0.8
62	0.95	0.01008	0.8
63	0.83	0.02856	0.8
64	0.7	0.0458	0.8
65	0.59	0.05806	0.8
66	0.5	0.06618	0.8
67	0.37	0.07376	0.8
68	0.26	0.07454	0.8
69	0.17	0.06911	0.8
70	0.1	0.05854	0.8
71	0.05	0.04443	0.8
72	0.025	0.03268	0.8
73	0.01	0.02129	0.8
74	0.0025	0.01089	0.8
75	0.00025	0.0035	0.8
76	0.00025	-0.0035	0.8
77	0.0025	-0.01089	0.8
78	0.01	-0.02129	0.8
79	0.025	-0.03268	0.8
80	0.05	-0.04443	0.8
81	0.1	-0.05854	0.8
82	0.185	-0.07053	0.8
83	0.26	-0.07454	0.8
84	0.355	-0.07422	0.8
85	0.49	-0.06695	0.8
86	0.59	-0.05806	0.8
87	0.7	-0.0458	0.8
88	0.835	-0.02784	0.8
89	0.95	-0.01008	0.8
90	0.98	-0.00504	0.8
91	0.98	0.00504	0.9
92	0.95	0.01008	0.9
93	0.83	0.02856	0.9
94	0.7	0.0458	0.9
95	0.59	0.05806	0.9
96	0.5	0.06618	0.9
97	0.37	0.07376	0.9
98	0.26	0.07454	0.9
99	0.17	0.06911	0.9
100	0.1	0.05854	0.9
101	0.05	0.04443	0.9
102	0.025	0.03268	0.9
103	0.01	0.02129	0.9
104	0.0025	0.01089	0.9
105	0.00025	0.0035	0.9
106	0.00025	-0.0035	0.9
107	0.0025	-0.01089	0.9
108	0.01	-0.02129	0.9
109	0.025	-0.03268	0.9
110	0.05	-0.04443	0.9
111	0.1	-0.05854	0.9
112	0.185	-0.07053	0.9
113	0.26	-0.07454	0.9
114	0.355	-0.07422	0.9
115	0.49	-0.06695	0.9
116	0.59	-0.05806	0.9

Table 12 Pressure Transducer Location

No.	x/c	y/c	z/s
117	0.7	-0.0458	0.9
118	0.835	-0.02784	0.9
119	0.95	-0.01008	0.9
120	0.98	-0.00504	0.9
121	0.98	0.00504	0.94603
122	0.95	0.01008	0.94603
123	0.83	0.02856	0.94603
124	0.7	0.0458	0.94603
125	0.59	0.05806	0.94603
126	0.5	0.06618	0.94603
127	0.37	0.07376	0.94603
128	0.26	0.07454	0.94603
129	0.17	0.06911	0.94603
130	0.1	0.05854	0.94603
131	0.05	0.04443	0.94603
132	0.025	0.03268	0.94603
133	0.01	0.02129	0.94603
134	0.0025	0.01089	0.94603
135	0.00025	0.0035	0.94603
136	0.00025	-0.0035	0.94603
137	0.0025	-0.01089	0.94603
138	0.01	-0.02129	0.94603
139	0.025	-0.03268	0.94603
140	0.05	-0.04443	0.94603
141	0.1	-0.05854	0.94603
142	0.185	-0.07053	0.94603
143	0.26	-0.07454	0.94603
144	0.355	-0.07422	0.94603
145	0.49	-0.06695	0.94603
146	0.59	-0.05806	0.94603
147	0.7	-0.0458	0.94603
148	0.835	-0.02784	0.94603
149	0.95	-0.01008	0.94603
150	0.98	-0.00504	0.94603
151	0.98	0.00504	0.9719
152	0.95	0.01008	0.9719
153	0.83	0.02856	0.9719
154	0.7	0.0458	0.9719
155	0.59	0.05806	0.9719
156	0.5	0.06618	0.9719
157	0.37	0.07376	0.9719
158	0.26	0.07454	0.9719
159	0.17	0.06911	0.9719
160	0.1	0.05854	0.9719
161	0.05	0.04443	0.9719
162	0.025	0.03268	0.9719
163	0.01	0.02129	0.9719
164	0.0025	0.01089	0.9719
165	0.00025	0.0035	0.9719
166	0.00025	-0.0035	0.9719
167	0.0025	-0.01089	0.9719
168	0.01	-0.02129	0.9719
169	0.025	-0.03268	0.9719
170	0.05	-0.04443	0.9719
171	0.1	-0.05854	0.9719
172	0.185	-0.07053	0.9719
173	0.26	-0.07454	0.9719
174	0.355	-0.07422	0.9719
175	0.49	-0.06695	0.9719
176	0.59	-0.05806	0.9719
177	0.7	-0.0458	0.9719
178	0.835	-0.02784	0.9719
179	0.95	-0.01008	0.9719
180	0.98	-0.00504	0.9719
181	0.17	0.06911	0.92302
182	0.37	0.07376	0.92302
183	0.59	0.05806	0.92302
184	0.83	0.02856	0.92302
185	0.37	0.07376	0.86667
186	0.59	0.05806	0.86667
187	0.83	0.02856	0.86667
188	0.59	0.05806	0.83333
189	0.83	0.02856	0.83333
190	0.83	0.02856	0.77619
191	0.5	0.06618	0.35
192	0.1	0.05854	0.1

Table 13 Layout of Run Information Block

RIB LOCATION	STATIC/ UNSTEADY STATIC	SINUSOIDAL	RAMP UP/ RAMP DOWN
0	Run Number		
1	Date of Test: Day		
2	Date of Test: Month		
3	Date of Test: Year		
4	Temperature (^{o} Celsius)		
5	Barometric Pressure (mm Hg)		
6	Motion Type (0)	Motion Type (1)	Motion Type (2/3)
7	Starting Incidence(^{o})	Mean Incidence (^{o})	Starting Incidence(^{o})
8	Arc (^{o})	Amplitude (^{o})	Ramp Arc (^{o})
9	Empty	Oscillation Frequency (Hz)	Linear Pitch-Rate ($^{o}\,s^{-1}$)
10	Number of Samples in One Block		
11	Number of Total Samples		
12	Number of Data Blocks (Cycles)		
13	Sampling Frequency (Hz)		
14	Dynamic Pressure (Psi)		
15	Reynolds Number		
16	Mach Number		
17	Empty	Reduced Frequency	Reduced Pitch-Rate
18	Incoming Velocity (ms^{-1})		
19	Dynamic Pressure (Nm^{-2})		
20	Model Number		
21	File ID		

Table 14 Data presented in each row of file cp***.dat**

Channels 1-192	Pressure coefficients corresponding to the transducer locations in Table 5.4
Channel 193	Temperature Channel (Uncalibrated since RIB contains temperature)
Channels 194-196	Accelerometer channels (units of g) (Channel 195 Faulty)
Channels 197-198	Empty
Channel 199	Incidence (deg)
Channel 200	Dynamic Pressure (psi)

Table 15 Data presented in each row of file ntm***.dat**

Position in row	Description of Parameter
1	Angle of Incidence (deg)
2 – 7	Integrated Cn for span stations 57.14%, 68.1%, 80%,90%,94.6%,97.2%
8 - 13	Integrated Ct for span stations 57.14%, 68.1%, 80%,90%,94.6%,97.2%
14–19	Integrated Cm for span stations 57.14%, 68.1%, 80%,90%,94.6%,97.2%
20	Integrated Cn for full wing
21	Integrated Ct for full wing
22	Integrated Cm for full wing

ST – Static RU – Linear Ramp-up RD – Linear Ramp-Down S – Sinusoidal

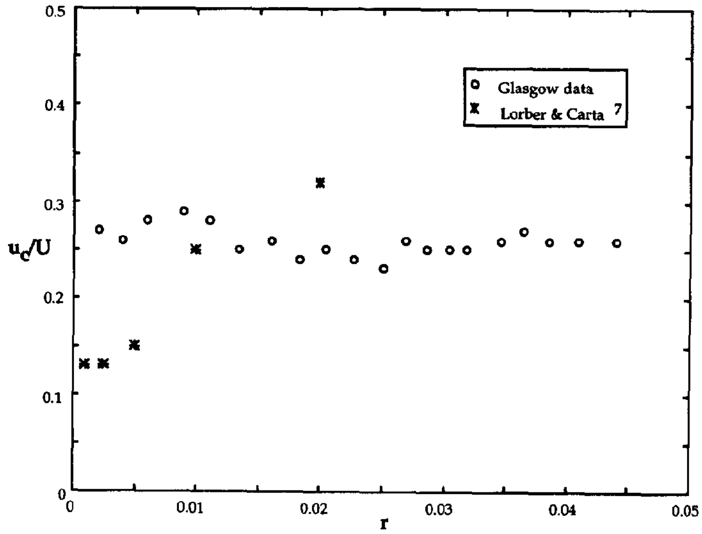

Fig 1 Variation of dynamic stall vortex convection with reduced pitch rate for the SSC-A09 tested at Glasgow. Lorber & Carta [7] results are also shown.

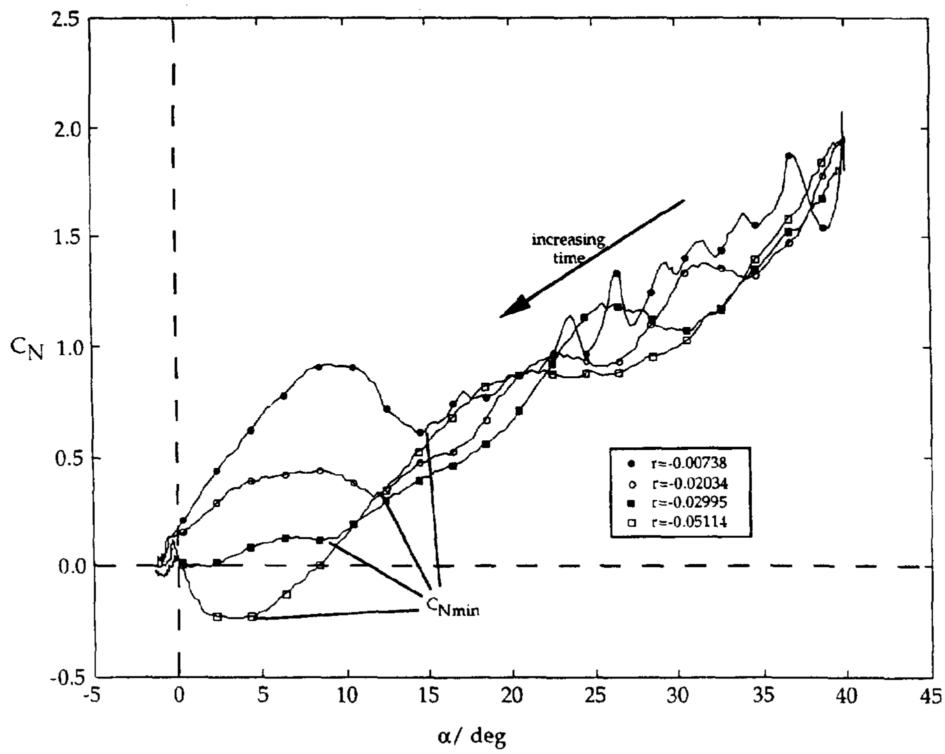

Fig 2 Normal force coefficient as a function of incidence during ramp-down tests of the Sikorsky SSC-A09 aerofoil. Normal Mach and Reynolds numbers are 0.12 and 1.5 million. The effect of reduced pitch rate is shown. Note the indicence at which C_{Nmin} occurs for each test case.

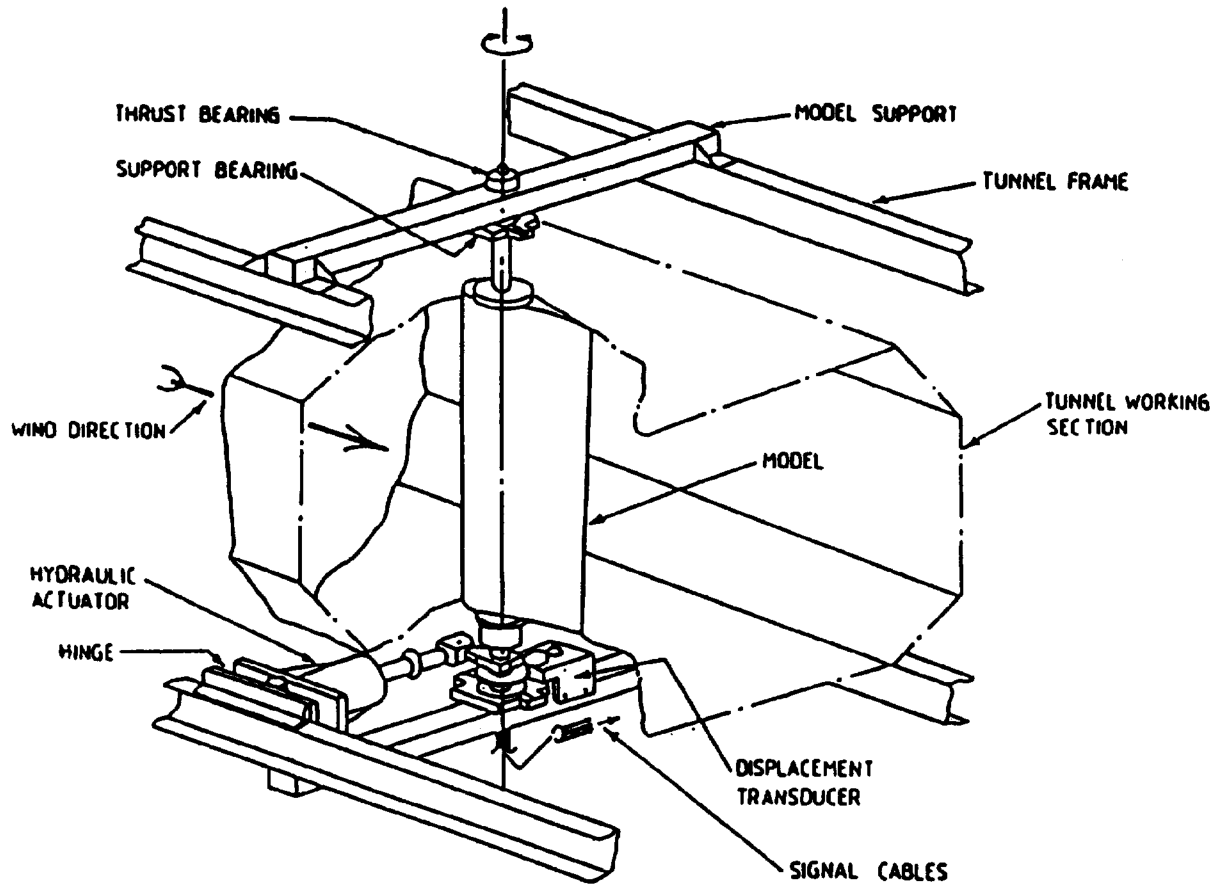

Fig 3 Installation of the Sikorsky SSC-A09 model in the Handley-Page wind tunnel

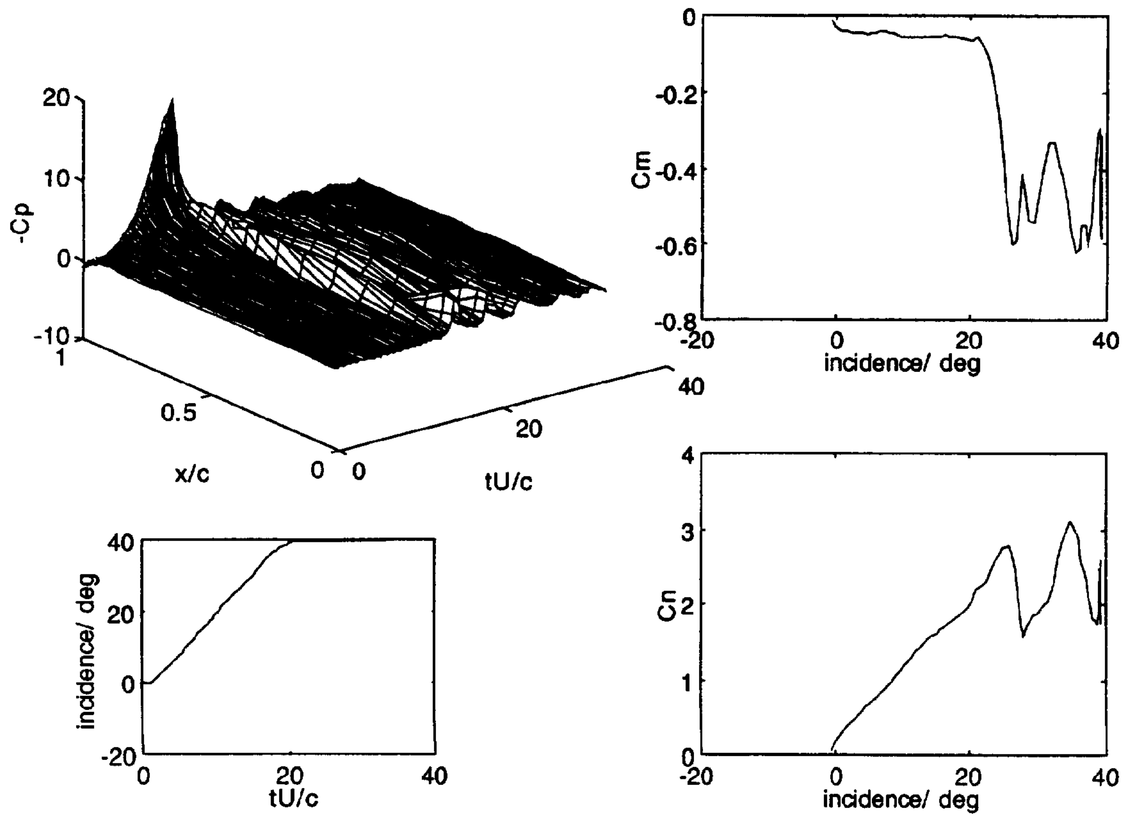

Fig 4 Pressure, normal force and pitching moment behaviour during ramp-up motion for the Sikorsky SSC-A09. r=0.02

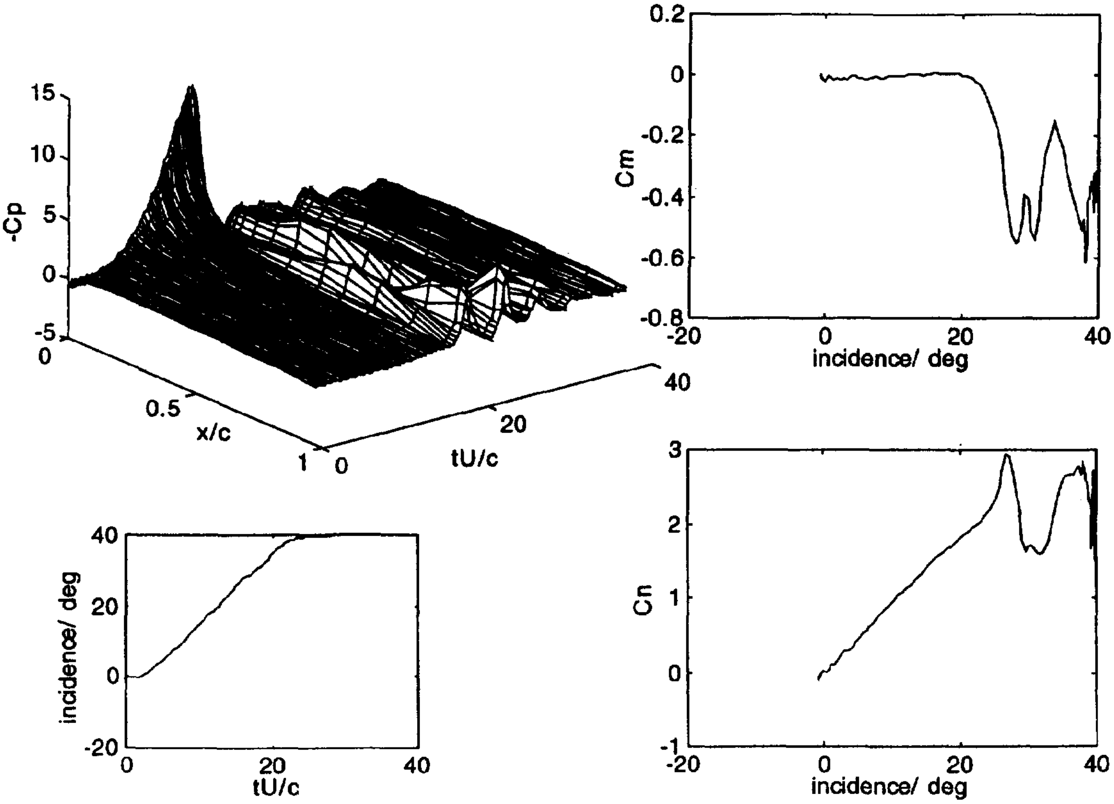

Fig 5 Pressure, normal force and pitching moment behaviour during ramp-up motion for the full chord NACA 0015. r=0.0187

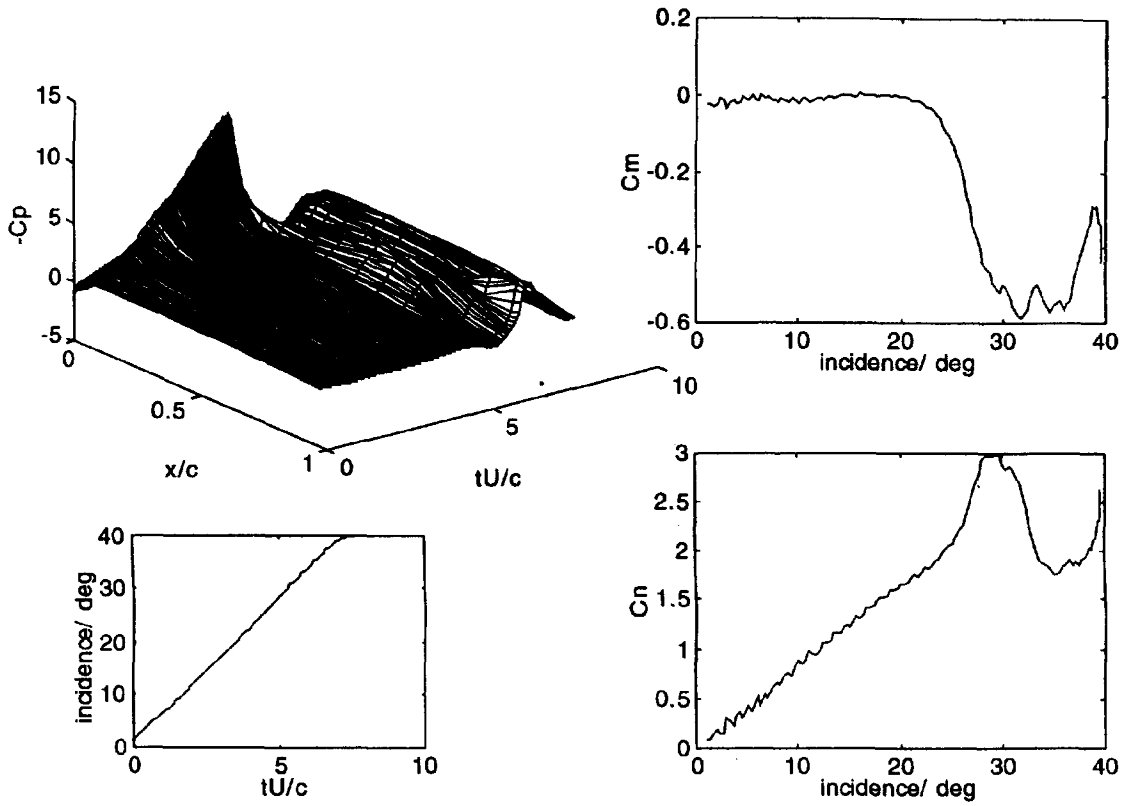

Fig 6 Pressure, normal force and pitching moment behaviour during ramp-up motion for the high aspect ratio NACA 0015. r = 0.0188.

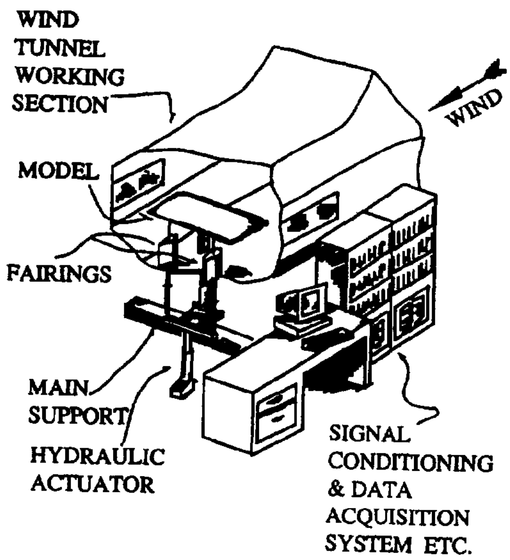

Fig 7 Test set-up for 3-D dynamic stall tests

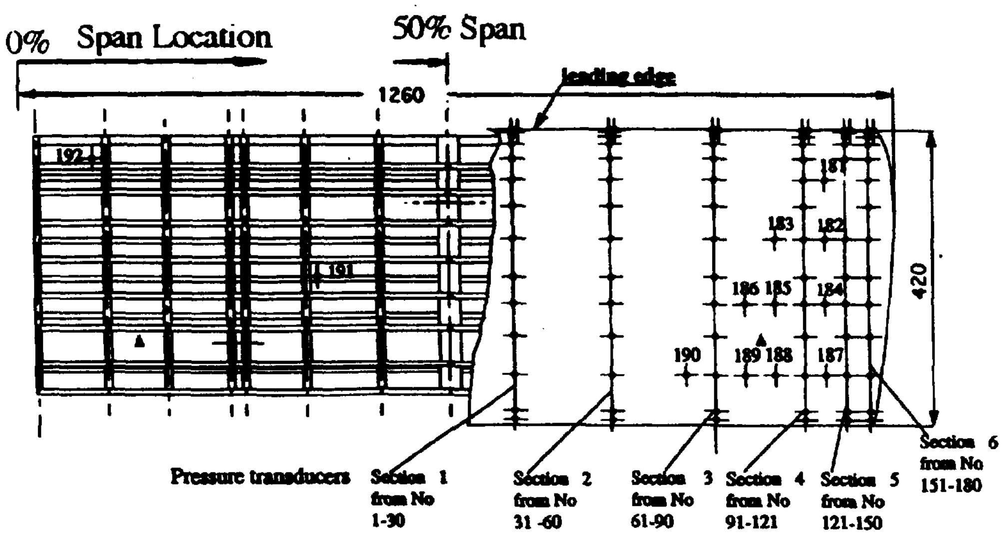

Fig 8 Rectangular wing model showing transducer placement
(▲ accelerometers)

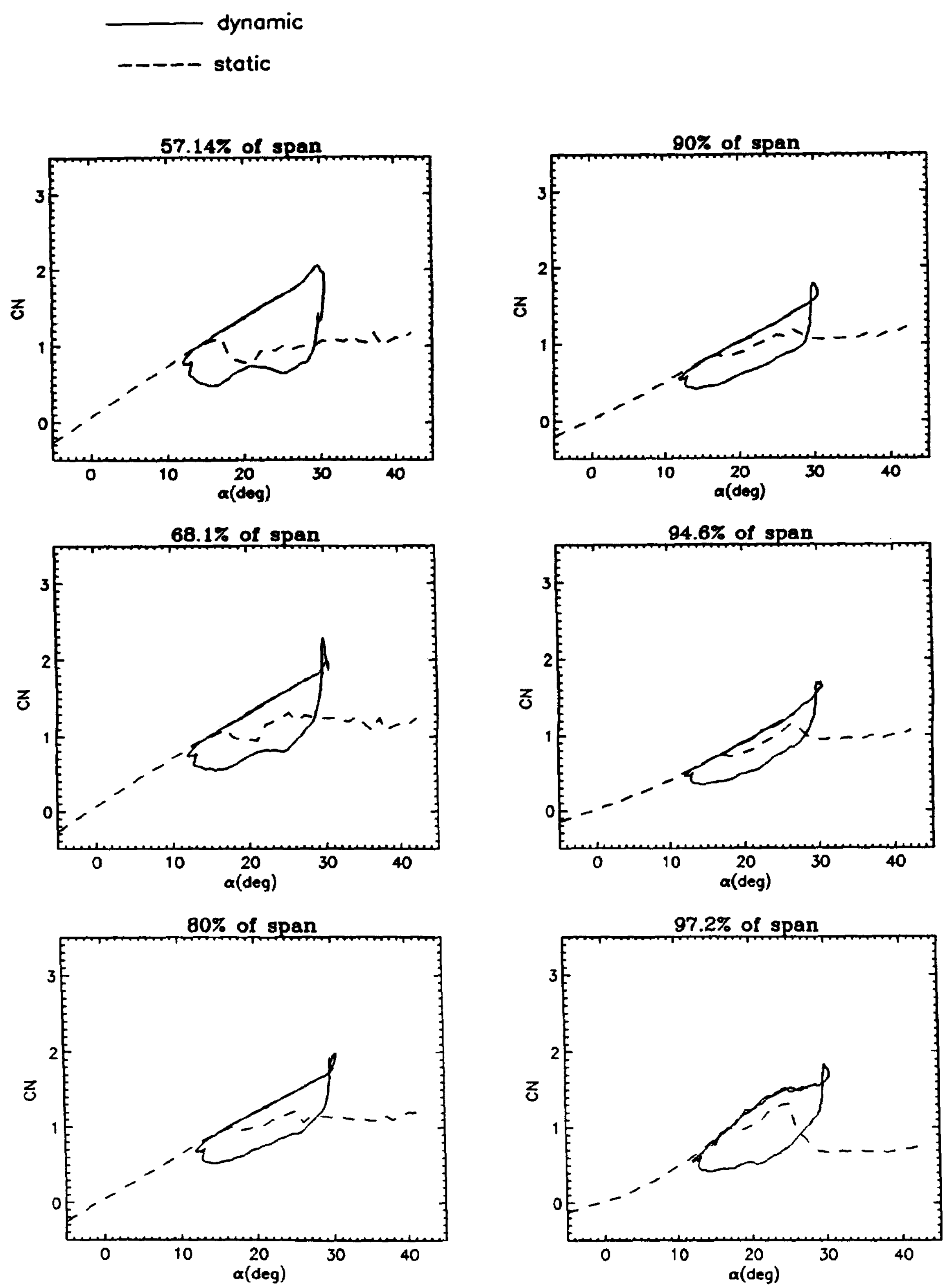

Fig 9 C_n against incidence at six span locations (case 11441)

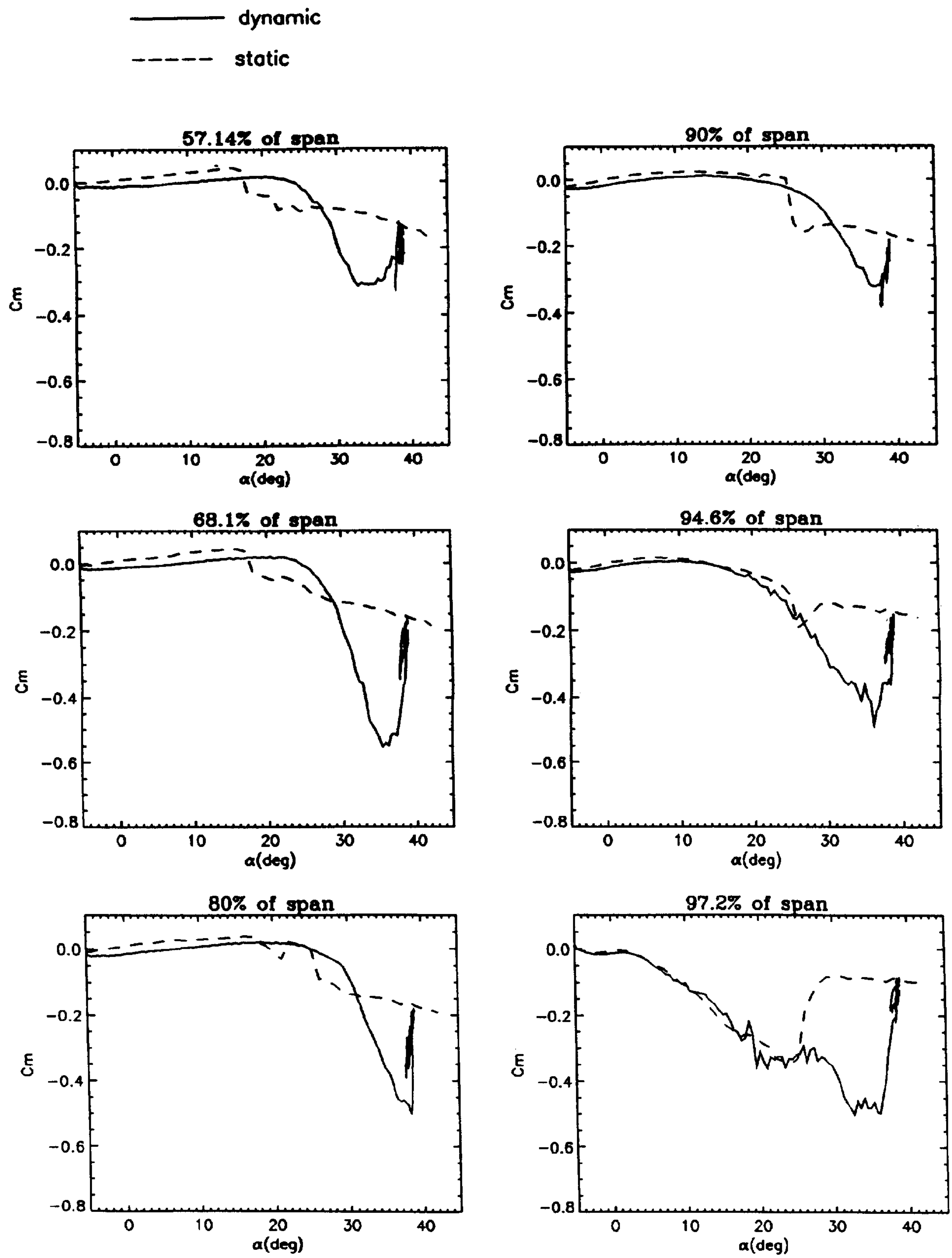

Fig 10 C_m against incidence at six span locations (case 20962)

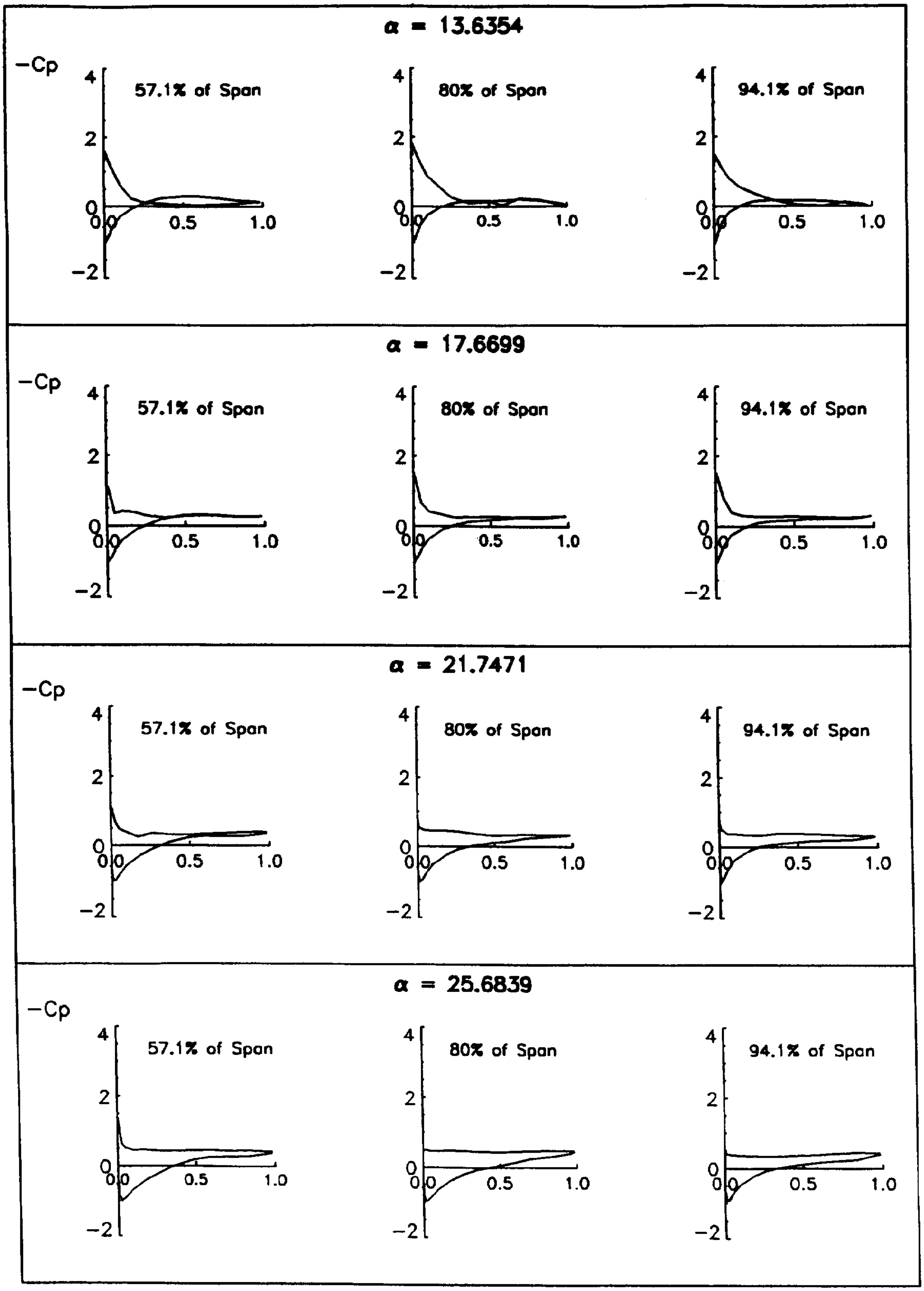

Fig 11 Chordwise pressure distributions (case 30681)

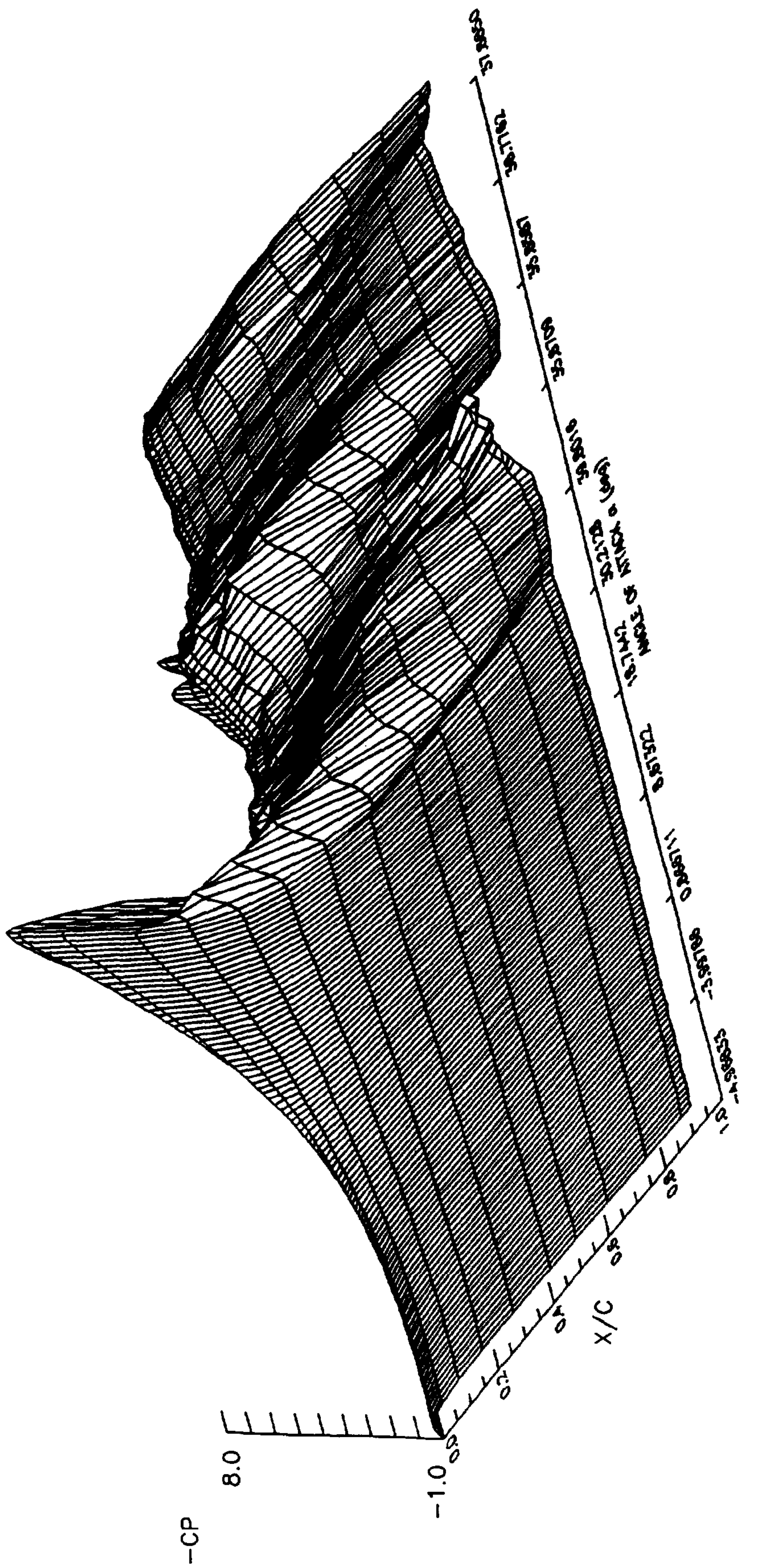

Fig 12 Upper surface variation of chordwise pressure at 57.14% span (case 21042)

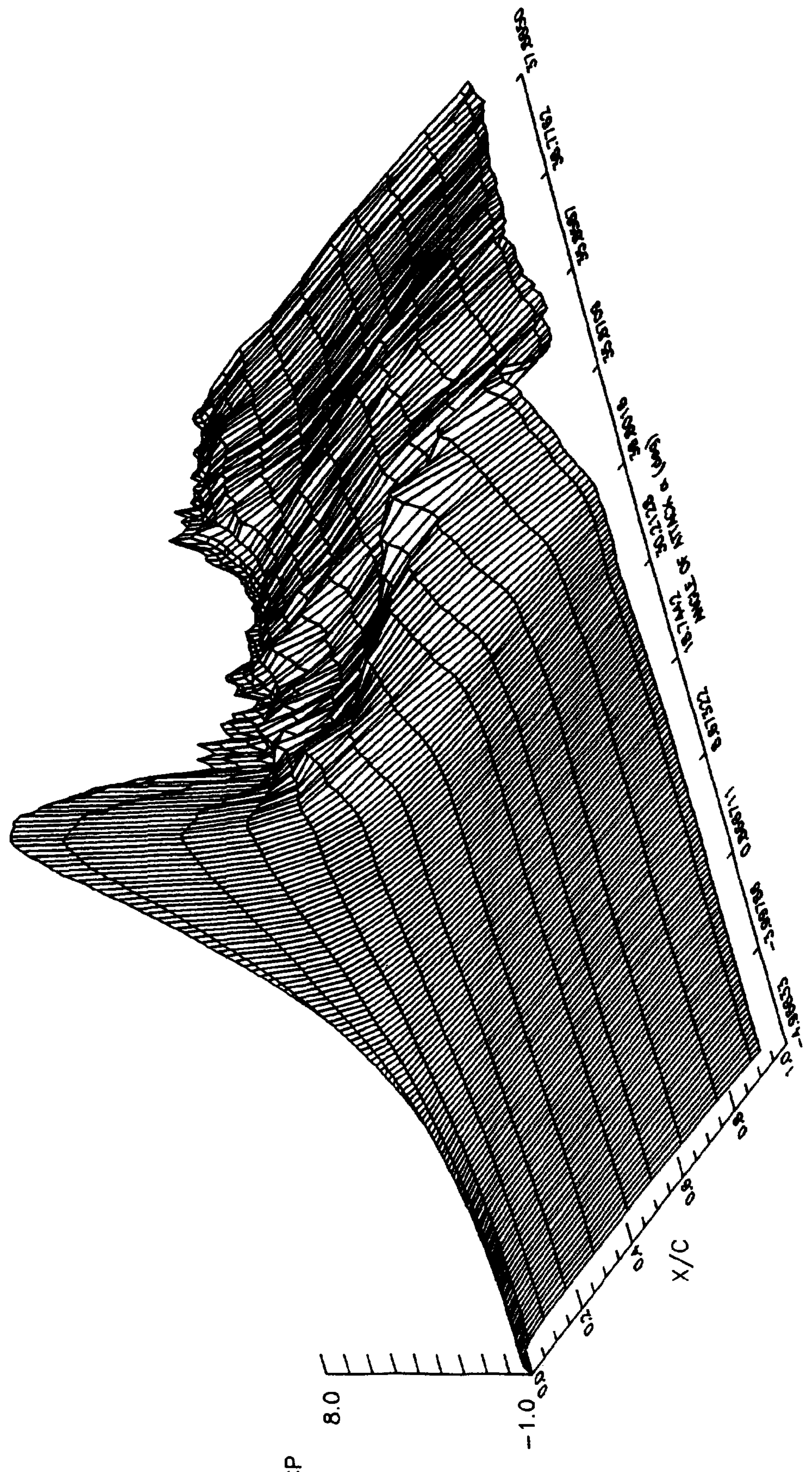

Fig 13 Upper surface variation of chordwise pressure at 80% span (case 21042)

Fig 14 Upper surface variation of chordwise pressure at 97.2% span (case 21042)